A SPACIAL BEHAVIOUR OF A NINE STORIES SRC BUILDING DURING THE MIYAGIOKI EARTHQUAKE, 1978

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SUMMARY

Necessity of spacial response analyses of buildings is emphasized on the basis of sample calculations and damage observations of a nine-stories SRC building equipped with two sets of three-components SMACS, one of which recorded the maximum value of 1_g at the ninth floor during the Miyagioki Earthquake, 1978; effects of torsional motions are very significant to the stability of buildings, walls contribute much to the stiffness and strength of the structure not only in horizontal but also in vertical directions, and local vibrations produced in the structure are not necessarily negligible.

BACKGROUND

A nine-stories SRC building (concrete structure reinforced with steel frames and steel bars), where our office and laboratory are situated, was severly shaken and many cracks were produced in walls, columns, beams and floors by the Miyagioki Earthquake, 1978.

Some professors and students were outside of the building when the earthquake took place, and observed its remarkably torsional motions and local deformations. Crack investigations proved also what the people saw from outside. This kind of behaviour can not be simultated with simple models commonly used in the structural-design-process. On the other hand, design earthquake excitations to structures are unable to be so precise that they are worthy for very realistic and complicated models.

We have analyzed the three dimensional behaviour of the soil and building by newly a developed computer program. After checking the correspondence of computed and recorded motions of the building, an ensemble of simulated earthquakes are produced in the computer by available data such as fault mechanisms, geological structures and soil conditions. (Soil-structure models are made by subspace methods from a detailed model of about ten thousands D.F.(degrees of freedom); the simplest one contains only nine D.F..)

MODAL ANALYSES

The building consists of three parts; a nine stories office building and two wings of two stories which are mainly for school rooms (Fig.2.1). It locates at the top of a hill and is supported by a stiff loam layer through PC piles of about twelve meters. Two types of spacial models were made through a finite element process; without the ground (fixed to the ground) and with piles and soils. Their mode shapes are illustrated in Fig.2.2 and Fig.2.3. The lowest torsional mode appears in the third mode and wing parts are strongly shaked in the fourth and fifth modes. The eighth, ninth and tenth modes show that the southern half of the office building (front in the figures) is vertically excited where no bearing walls are inserted in the frame except the both sides. Problems inherent in this kind of finite element treatments are concerning the boundaries of the grounds, and there have been several proposals.[1] In order to find out the simple and convenient boundary-assumptions, transfer functions of modal points at the center and on the boundary are checked under various assumptions with a FEM model of an unloaded soil block. Fig.2.4 and 2.5 show their comparisons in a free-boundary model and a roller-boundary model, and the latter shows a good result. (Transfer function on the boundary differs from that at the center in the free-boundary model, while they are very similar to each other in the roller-boundary model.)

Natural periods of the building were investigated before and after earthquakes and they were found to be elongated.[2,3]
The calculated natural periods from the models are close to those observed immediately after the construction of the building. The slight differences may be caused the simplification of details in the models (Table 2-1).

TRANSFER FUNCTIONS

Comparisons of linear behaviour of complicated FEM models and simple mass-spring systems were made in their transfer functions. The damping ratio of the first mode was assumed to be 3%. Transfer functions of a FEM model without the ground are very similar to those of a mass-spring system fixed at the end. However, torsional effects are entirely neglected in the latter which was made from world-widely used method; plane frames. Besides, natural frequencies become higher except the fundamental ones in the simple model than those of the FEM model, giving lesser effects to the response of the structure in the whole. When the piles and soils are included in the models, the above mentioned tendencies become more evident, and one may say that an example of simple and good models is a spacial mass-spring system, and effect of local vibration should be considered in the structural design (Fig. 3.1 to 4).

RESPONSE CALCULATION

Elongation of the natural periods mainly means extension of local damage such as separation of finishing from the structural members, production of cracks in walls, etc., and partially means increase of live loads, such as accumulations of books and papers, increase of furnitures and instruments. These also contribute to increase the damping of the building.

The response calculations in the time domain were made regardless the changes and the results are shown in figures (4.1∿4.3). The first records were obtained on 14, Sept., 1970 (Max. Values were 33.4$_{gals}$ in NS and 14.4 gals in UD on the ground floor). The structure behaved linearly, and the recorded response and calculated one are alike. Earthquakes occured in 1978 (20, Feb. and 12, June) were much stronger and figures show the very different tendencies in the recorded and calculated responses. (Max. values are 114$_{gals}$ and 202$_{gals}$ in EW, 170$_{gals}$ and 258$_{gals}$ in NS and 95$_{gals}$ and 154 gals in UD on the ground floor respectively.)

Non-linear response calculations were made for a simple mass-spring system, and obtained accordance with the observed response. But torsional motions are neglected, and non-linear analyses in FEM spacial models are much complicated and require many assumptions to simplify the models.

ANALYSES OF NON-LINEAR BEHAVIOUR

Generally, non-linear response analyses of structures are carried out with restoring force diagrams assumed from test-results of structural members. But non-linearity of spacial structures including torsional deformations are hardly estimated from the member-tests. Consequently other kinds of approaches are needed. One possibility is application of 'Wiener's Theory of Non-Linear System' [4,5] to earthquake engineering, by which non-linear characteristics of structures are obtained from input and output records; the linear and non-linear responses are separated and equivalent stiffness and damping are obtained (Fig.5.1).

In this method, however, significant effects of non-stationary characteristics of seismic waves to non-linear behaviours of structures are neglected.

SIMULATION OF NON-STATIONARY EARTHQUAKES

A method[6] to simulate ensembles of non-stationary earthquakes has been developed on the basis of informations such as "phase inclinations: $t_{gr}(\omega) = d\phi(\omega)/d\omega$", and it enables one to introduce non-stationary characteristics caused by mechanisms of faults and wave-paths. Fig.6.1 and 2 show an assumed $t_{gr}(\omega)$ and a non-stationary waves obtained by the $t_{gr}(\omega)$. From a fault model of the Miyagioki Earthquake, 1978 non-stationary base rock motions were calculated (Fig.6.2) and used as the input to a simple mass-spring model of soil layers and the nine-stories SRC building. Table 6.1 shows the maximum response of the structures and the time when they took place. A non-stationary wave shwon in Fig.6.2 was obtained from $t_{gr}(\omega)$, which was so assumed that the wave might have predominant compnents of low. frequencies($0 \sim 1\ H_z$) around 20 sec. and those of frequencies around $10 \sim 15$sec. corresponded to the range where values of transfer function of a model are big. The maximum values of response accelerations and velocities appeared around 15sec. while displacements reached their maximum around 21sec., showing that displacements which were sensitive to input long wave were influenced by non-stationarity given through $t_{gr}(\omega)$.

CONCLUSION

Observations of the behaviour and damage investigations show the necessity of spacial response analyses of structures to earthquakes. Through modal and linear response analyses it has become clear that a very simple model sufficiently represents the real behaviour of the original structure, provided that the effects of local vibration are considered in the structural design process. But the non-linear behaviours include various problems. Three dimensional finite-element approach is a solution but it consumes time and money and it is almost impossible to get sufficient data to one's stochastic treatment. In order to get a simple model another approach was tried in the paper as an application of Wiener's theory.
Equivalent stiffness and damping are obtained and transfer functions according as the input energy levels are available, if the input is Gussian. Therefore, this is a method to make simple non-linear models.
However, earthquake motions are not stationary and much influence non-linear behaviours of structures. Ensembles of non-stationary earthquakes can be produced in computers from assumed fault models and wave-paths through phase inclinations.

Concerning the behaviour of this nine stories SRC building, torsional motions obtained from the analyses were not so big as the observed ones. Possible reasons are: damping correspond to torsional motions may be relatively small and there exists torsional components in the ground motion such as components of Love's wave. So new types of data become important; spacial structural behaviours obtained from many strong motion accelerographs distributed to a structure and to the site.

ACKNOWLEDGMENT

This study was carried out under guidance of Prof. M.IZUMI, Tohoku Univ. Computer programs[7] used are those developed in Struct. Mech. Lab. Arch. Dept., where authors belong to.

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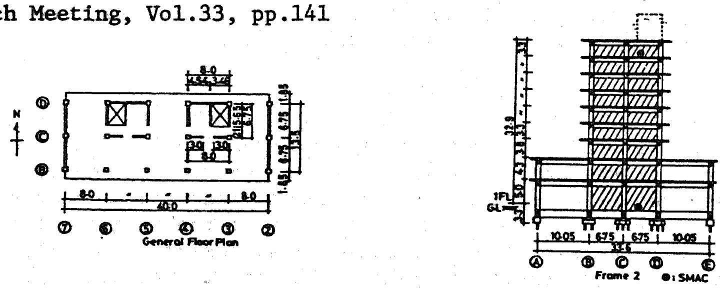

Fig. 2-1 Nine Stories SRC Univ. Building

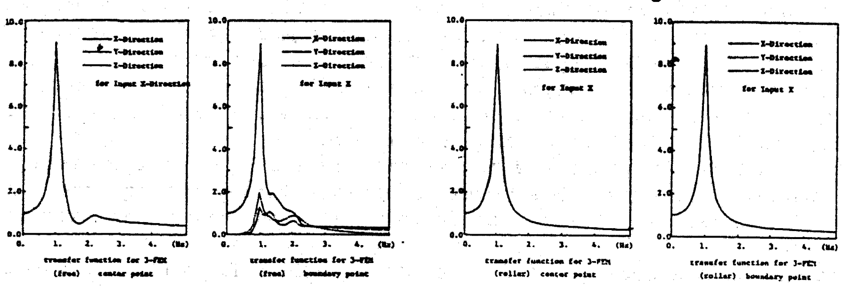

Fig. 2-4&5 Transfer Function of Ground Model (With Free & Roller Bound.)

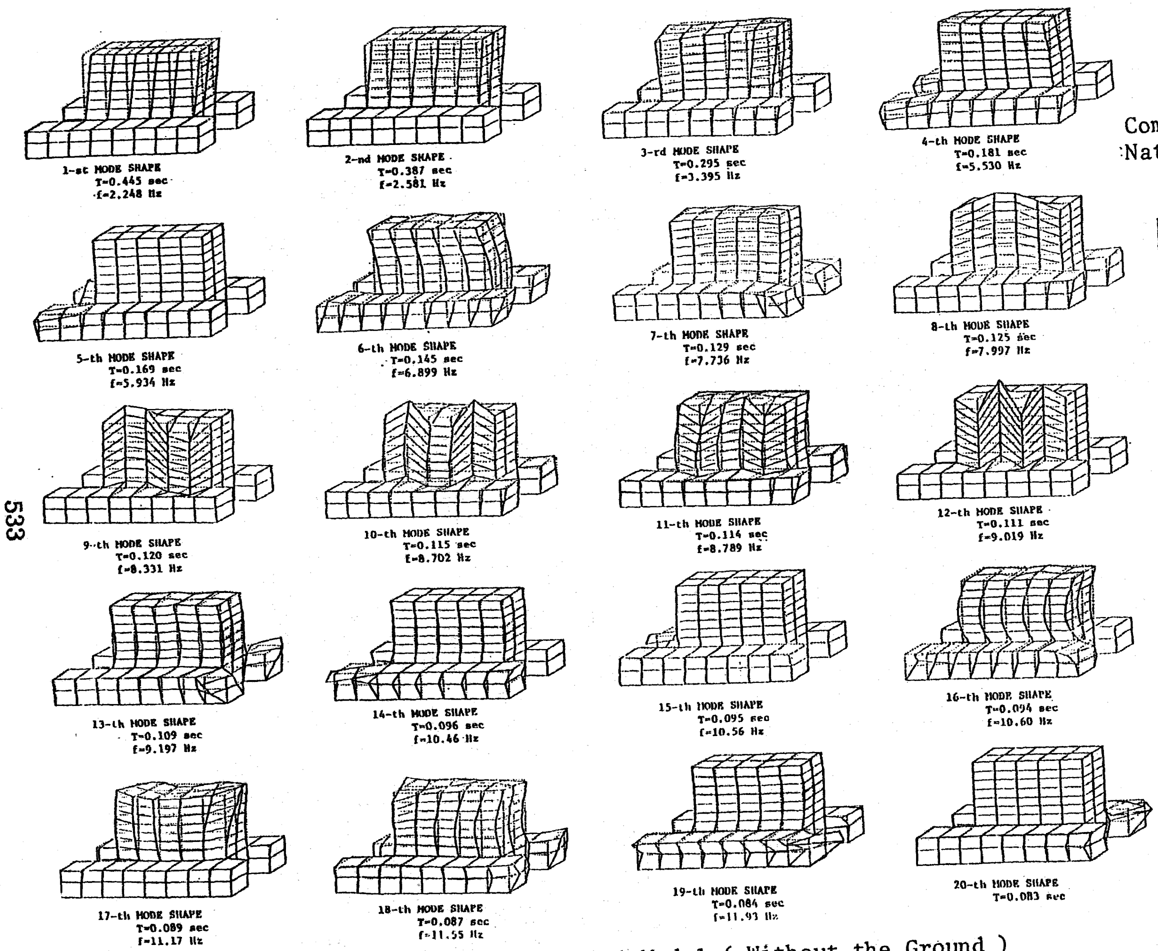

Fig. 2-2 Mode Shape of Spacial Model (Without the Ground)

Table 2-1

Comparison of Fundamental Natiral Periods (sec.)

	NS	EW
FEM Model (without Ground)	0.38	0.44
FEM Model (with Ground)	0.49	0.55
Measured[2] (Before Quakes)	0.44	0.41
SMAC DATA[3] (Feb.'78)	0.50	0.47
SMAC DATA (June'78)	0.80	
Measured (After Quakes)	0.67	0.63

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III) Graduate Student, Tohoku Univ.

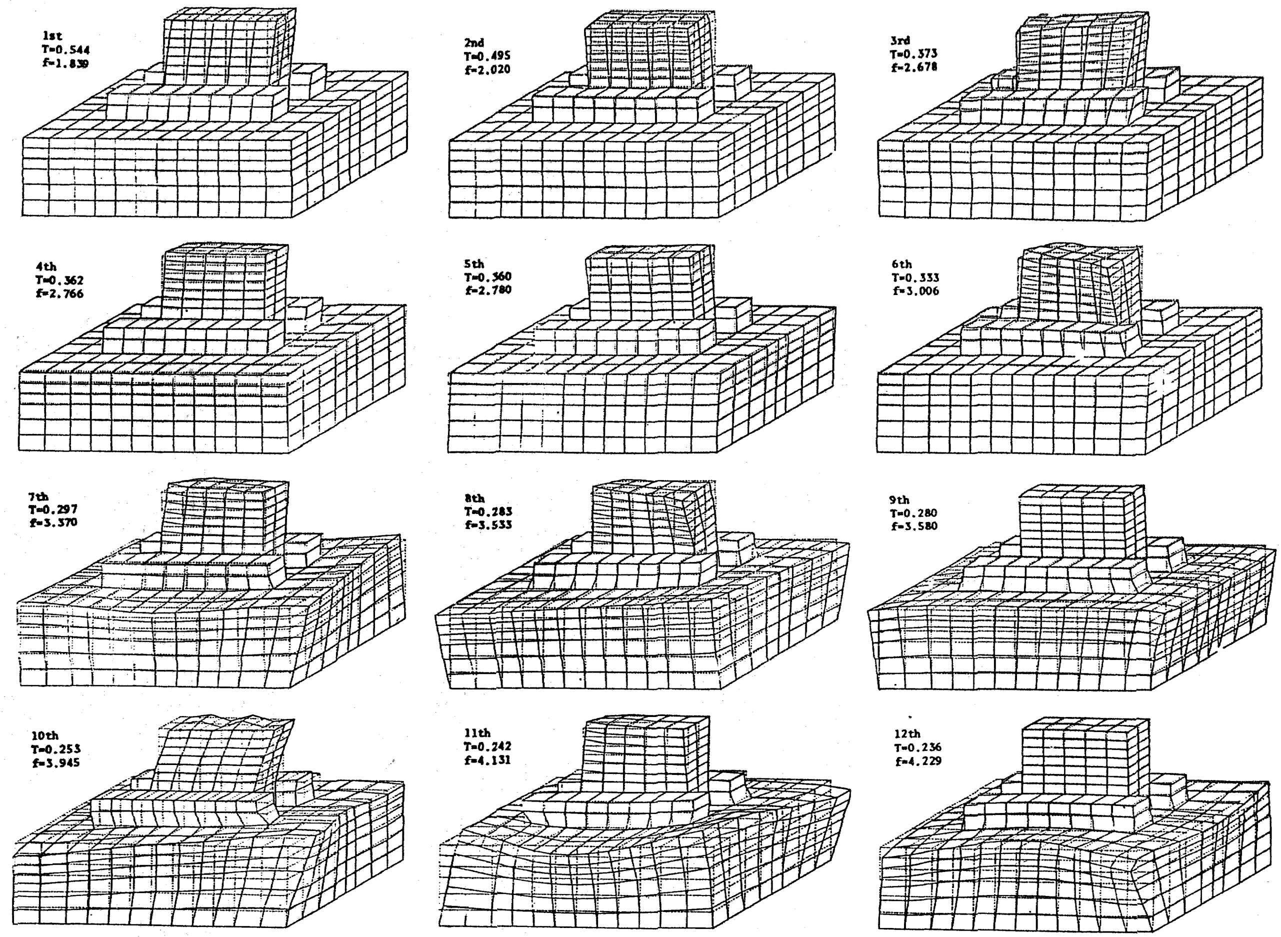

Fig. 2-3 Mode Shape of Spacial Model (With the Ground)

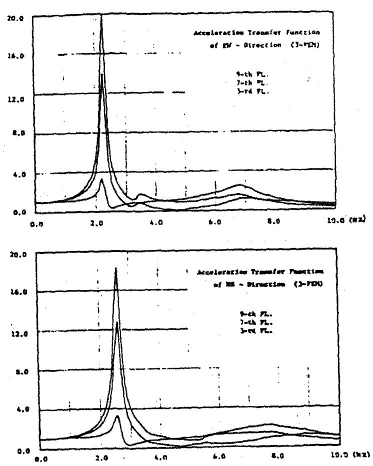

Fig. 3-1 Transfer Function of FEM Spacial Model (Without the G.)

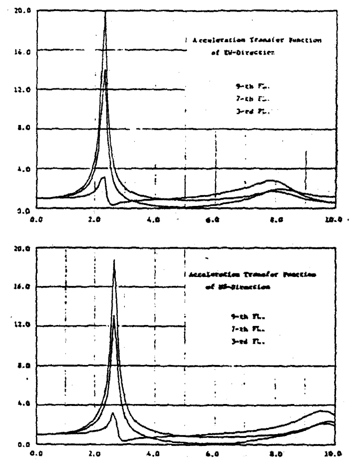

Fig. 3-2 Transfer Function of a Simple Mass-Spring Model (Without G.)

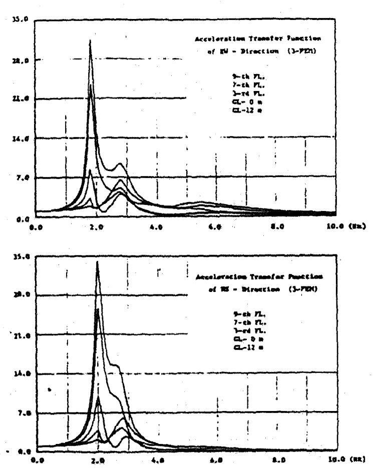

Fig. 3-3 Transfer Function of FEM Spacial Model (With the Ground)

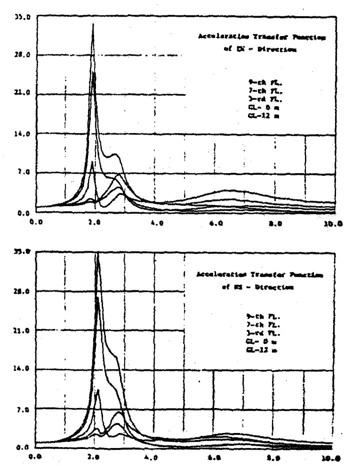

Fig. 3-4 Transfer Function of a Simple Mass-Spring Model (With the G.)

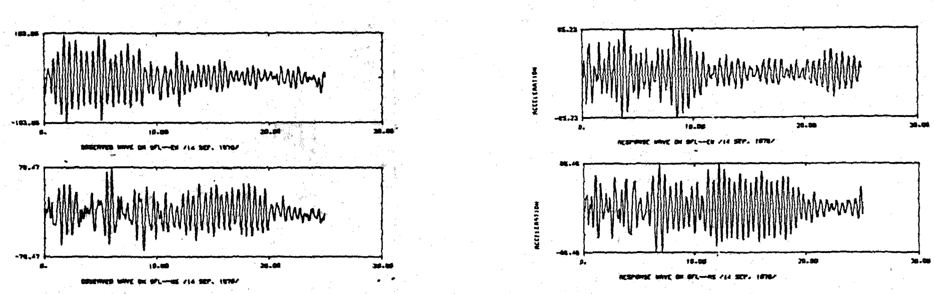

Fig. 4-1 Response to Earthqu. 14 Sept.,'70 (Recorded & Calculated)

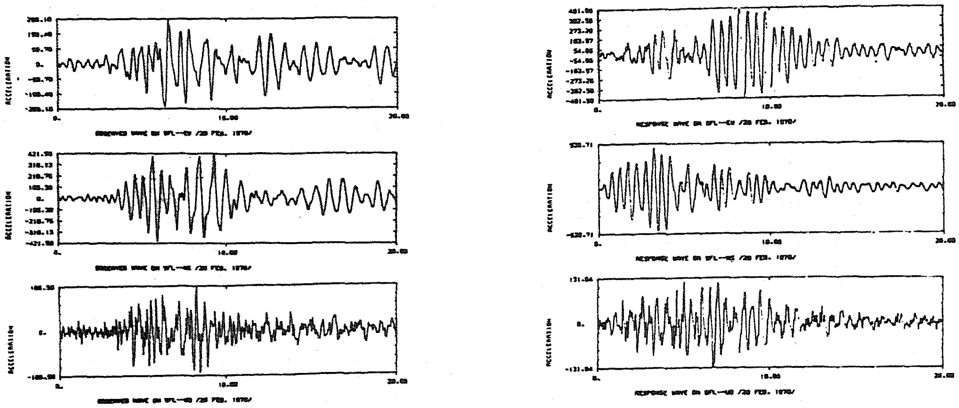

Fig. 4-2 Response to Earthqu. 20 Feb.,'78 (Recorded & Calculated)

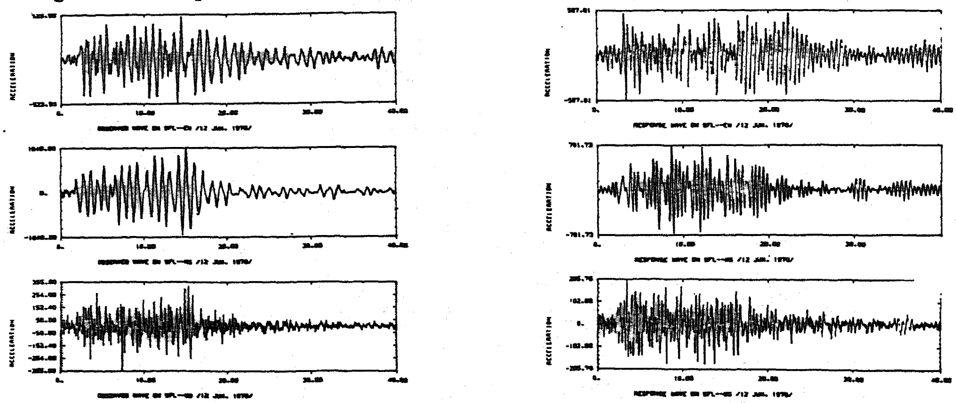

Fig. 4-3 Response to Earthqu. 12 June,'78 (Recorded & Calculated)

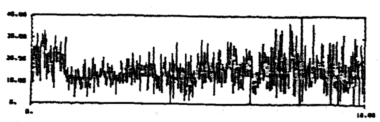

Fig. 6-1 T_{gr} (Assumed)

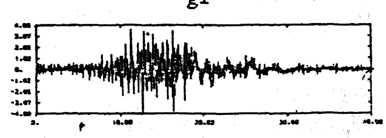

Fig. 6-2 Simulated Wave

Table 6-1 **Maximum Response Value for One gal Baserock Motion**

A_{max} = 51.4 $^{cm}/_{sec^2}$	(15.2^{sec})
V_{max} = 2.87 $^{cm}/_{sec}$	(14.9^{sec})
D_{max} = 0.278^{cm}	(21.1^{sec})

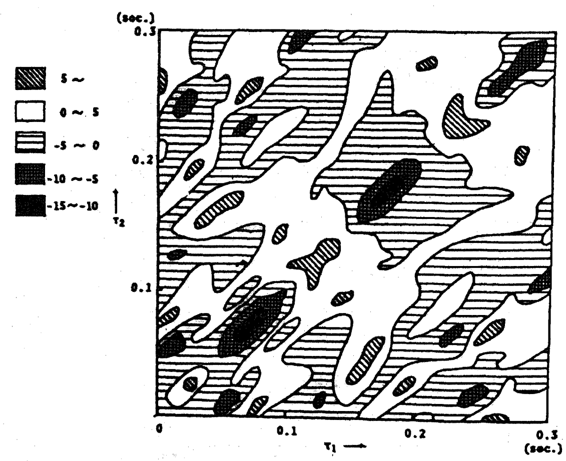

Fig. 5-1 Wiener's Non-Linear Kernel